British Journal of Nutrition (2005), **94**, 843–849 DOI: 10.1079/BJN20051551

Intra- and interindividual variability of resting energy expenditure in healthy male subjects – biological and methodological variability of resting energy expenditure

Nicolle Bader, Anja Bosy-Westphal, Britta Dilba and Manfred J. Müller*

Insititut für Humanernährung und Lebensmittelkunde der Christian-Albrechts-Universität zu Kiel, Germany

(Received 12 November 2004 – Revised 23 March 2005 – Accepted 12 April 2005)

The objective of the present study was to investigate the contribution of intra-individual variance of resting energy expenditure (REE) to interindividual variance in REE. REE was measured longitudinally in a sample of twenty-three healthy men using indirect calorimetry. Over a period of 2 months, two consecutive measurements were done in the whole group. In subgroups of seventeen and eleven subjects, three and four consecutive measurements were performed over a period of 6 months. Data analysis followed a standard protocol considering the last 15 min of each measurement period and alternatively an optimised protocol with strict inclusion criteria. Intra-individual variance in REE and body composition measurements (CV_{intra}) as well as inter-individual variance (CV_{inter}) were calculated and compared with each other as well as with REE prediction from a population-specific formula. Mean CV_{intra} for measured REE and fat-free mass (FFM) ranged from 5·0 to 5·6 % and from 1·3 to 1·6 %, respectively. CV_{intra} did not change with the number of repeated measurements or the type of protocol (standard *v*. optimised protocol). CV_{inter} for REE and REE adjusted for FFM (REE_{adj}) ranged from 12·1 to 16·1 % and from 10·4 to 13·6 %, respectively. We calculated total error to be 8 %. Variance in body composition (CV_{intra} FFM) explains 19 % of the variability in REE_{adj}, whereas the remaining 81 % is explained by the variability of the metabolic rate (CV_{intra} REE). We conclude that CV_{intra} of REE measurements was neither influenced by type of protocol for data analysis nor by the number of repeated measurements. About 20 % of the variance in REE_{adj} is explained by variance in body composition.

Resting energy expenditure: Intra-individual variance: Interindividual variance: Resting energy expenditure prediction

Individuals vary in their resting energy expenditure (REE). The majority of interindividual variance in REE (CV_{inter}) is explained by fat-free mass (FFM), fat mass (FM), age and sex, leaving only 19 % unexplained (Ravussin *et al.* 1986). Unexplained variance is mainly due to composition of FFM, genetic factors and thyroid hormone levels (Müller *et al.* 2002). In comparison with CV_{inter}, intra-individual variance in REE (CV_{intra}) is reported to be low (2–10 %; Soares & Shetty, 1986; Weststrate, 1993). However, CV_{intra} could partly explain the interindividual variance in REE observed in different studies by contributing to between-group differences (i.e. between normal-weight and overweight subjects). Intra-individual variance in REE is explained by biological and methodological variability in REE. Since FFM is the major determinant of REE, the biological and methodological variance in FFM adds to the variance in REE adjusted for FFM. Intra-individual variance in REE may also contribute to inaccuracies of REE prediction by both limiting the accuracy of databases for the generation of prediction formulas as well as the implementation of such a formula on the individual level. Applying established REE prediction equations (i.e. from Harris & Benedict, 1919; Anonymous, 1985) or a newly established algorithm generated from a recently published German database of REE (Müller *et al.* 2004) resulted in considerable standard errors of the estimates ranging from 0·77 to 0·83 MJ/d (Müller *et al.* 2004). Taking into account the reported range of 2–10 % CV_{intra} of REE measurements (Soares & Shetty, 1986; Weststrate, 1993), a significant proportion of the imprecision of REE prediction might be due to CV_{intra}.

The present study sets out to investigate CV_{intra} and CV_{inter} of REE in a homogeneous sample of young men, taking into account the intra-individual variance of body composition. Biological variability and methodological (technical) error were calculated. Two strategies were followed to reduce CV_{intra}. First, we investigated the number of measurements necessary to minimise CV_{intra}. Second, we compared a standard protocol of data analyses (last 15 min of REE measurement) to an optimised protocol of data analysis (including standardised criteria for data selection). The differences of measured and predicted REE were assessed to analyse precision of REE prediction. Finally, we searched for *a priori* identification of subjects who have a large CV_{intra} in REE measurements and whose results might therefore be interpreted with caution.

Methods

A sample of twenty-three healthy male volunteers (aged 21–43 years) was recruited by notice board postings. All but one subject were non-smokers. Each participant underwent a basal

Abbreviations: VCO_2, CO_2 production; CV_{inter}, interindividual variance in resting energy expenditure; CV_{intra}, intra-individual variance in resting energy expenditure; FFM, fat-free mass; FM, fat mass; REE, resting energy expenditure; REE_{adj}, REE adjusted for FFM.

* **Corresponding author:** Professor Manfred J. Müller, fax +49 431 8805679, email mmueller@nutrfoodsc.uni-kiel.de

examination (blood pressure and haemogram). The subjects were not taking any medication known to influence energy metabolism. They refrained from heavy exercise during the study period and were not dieting. Weight stability defined as a CV $<3\,\%$ over the study period was an inclusion criterion. The study was carried out over a period of 6 months comprising four measurements (T0 baseline, T1 37 ± 11 d, T2 95 ± 8 d and T3 170 ± 7 d from baseline). All subjects were investigated at T0 and T1. At T2, a subgroup of seventeen and at T3 a subgroup of eleven subjects were reinvestigated. The reasons for dropout of six subjects at T2 and another six at T3 were lack of interest (seven subjects), weight loss (two subjects), RQ $>$ 1·1 (one subject), non-fasting subject (one subject) and not lying motionless during REE measurement (one subject). Physical characteristics of the study group are presented in Table 1.

All measurements were conducted between 06.30 and 09.30 hours after an overnight fast of >8 h under out-patient conditions. Subjects were instructed to have adequate sleep the night before and to come to the institute by car. Body composition was obtained by air-displacement plethysmography (Bod POD® Body Composition System; Life Measurement Instruments, Concord, CA, USA). Body weight was measured on a coupled electronic scale to the nearest 0·01 kg. Standing height was assessed to the nearest 1·0 cm by a calibrated stadiometer with subjects in underwear and without shoes.

REE was measured by the ventilated hood system (Vmax model 29n, SensorMedics®; Viasys Healthcare, Bilthoven, The Netherlands) for 30 min after resting for 5 min during calibration of the system in a metabolic ward at constant humidity (55 %) and room temperature (22°C). A mass-flow sensor measured volume and airflow. Calibration of flow and gas analysers was done before each measurement. Flow calibration was performed by a 3 litre calibration syringe and gas analysers were calibrated using two standard gas concentrations (16 % O_2, 4 % CO_2; 26 % O_2; room air 20·94 % O_2, 0·05 % CO_2). During the measurements subjects were awake, and lay quietly and motionless. Data were collected every 20 s. VO_2 and CO_2 production (VCO_2) were converted to REE by using the abbreviated Weir equation (Weir, 1949): REE (kJ) $= 16{\cdot}18VO_2 + 5{\cdot}02VCO_2$. Two ways of data analysis were compared with regard to CV_{intra} of REE measurements. In a standard protocol the last 15 min of gas exchange measurements were evaluated whereas an optimised protocol included the following steady-state criteria for data analysis (Reeves *et al.* 2004): variation in VO_2 per min and VCO_2 per min $<10\,\%$. Thus, in the optimised protocol a mean period of 12 SD 5) min was analysed for calculation of REE.

REE was predicted by two recently published algorithms generated and validated in a German reference population (Müller *et al.* 2004), using either weight, sex and age (model 1):

$$\mathrm{REE(MJ/d)} = 0{\cdot}047 \times \mathrm{weight(kg)} + 1{\cdot}009 \times \mathrm{sex} - 0{\cdot}01\,452 \times \mathrm{age(years)} + 3{\cdot}21;$$

or FFM, FM, sex and age (model 2):

$$\mathrm{REE(MJ/d)} = 0{\cdot}05\,192 \times \mathrm{FFM(kg)} + 0{\cdot}04\,036 \times \mathrm{FM(kg)} + 0{\cdot}869 \times \mathrm{sex} - 0{\cdot}01\,181 \times \mathrm{age(years)} + 2{\cdot}992.$$

Table 1. Physical characteristics of the subjects*
(Mean values and standard deviations)

	Group 1 (*n* 23)						Group 2 (*n* 17)						Group 3 (*n* 11)					
	T0		T1		CV_{intra} (%)		T0		T1		T2		CV_{intra} (%)	T0		T1		T2		T3		CV_{intra} (%)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Age (years)	30	7	31	7			29	5	29	6	30	6		30	0 6	30	6	30	6	30	6			
Height (m)	182	8	182	8			181	8	181	8	181	0 8		180	8	180	8	180	8	180	8			
Weight (kg)	85·9	20·4	85·2	19·8	0·9	0·8	77·6	10·8	77·4	10·9	78·4	10·9	1·2	0·8	76·4	12·9	76·1	13·2	77·0	13·1	77·4	13·4	1·1	0·6
BMI (kg/m^2)	25·9	5·2	25·7	5·1	0·9	0·8	23·7	3·0	23·6	3·1	24·0	3·1	1·2	0·8	23·5	3·2	23·4	3·3	23·7	3·4	23·8	3·4	1·1	0·6
FFM (kg)	65·3	9·7	64·8	9·5	1·4	1·3	62·3	7·6	62·4	7·8	61·7	8·0	1·6	0·8	62·4	9·0	62·6	8·9	62·2	9·3	62·2	9·3	1·3	0·3
FM (%)	22·5	8·1	22·4	8·9	5·5	6·4	19·3	5·7	18·9	6·6	21·0	5·5	8·6	6·9	17·9	5·1	17·2	5·7	18·9	4·8	19·2	5·1	7·9	6·1

CV_{intra}, intra-individual CV; FFM, fat-free mass; FM, fat mass.
T0, baseline; T1, 37 ± 11 d; T2, 95 ± 8 d; T3, 170 ± 7 d.
*There were no significant differences between the subgroups in any of the measured variables (ANOVA and Bonferroni *post hoc* test). For details of groups and measurement protocol, see p

Data analyses

All data are given as means and standard deviations. CV_{intra} was calculated as SD/mean × 100 from repeated measures of one subject. CV_{inter} was calculated for between-subject data from each group (group 1, 2 and 3). Within-subject standard deviation was calculated as the square root of group mean SD^2 (Bland & Altman, 1996). Statistical analyses were performed using SPSS for Windows (version 9.0, 1998; SPSS Inc., Chicago, IL, USA). ANOVA with the Bonferroni adjusted *post hoc* test was used to analyse intra-individual data. Pearson's correlation coefficients were calculated for relationships between variables. All tests were two-tailed and a P value of 0·05 was accepted as the limit of significance. REE was adjusted for FFM and FM (REE_{adj}) according to Ravussin & Bogardus (1989) by using the following equation:

$$REE_{adj} = REE_{measured} + ((FFM_{group\ mean} - FFM_{measured}) \times slope).$$

Due to a limited number of subjects in the present study, $FFM_{group\ mean}$ and slope for adjustment of REE were derived from a large database (n 94, male, mean age 42 (SD 6) years, mean BMI 27·9 (SD 4·4) kg/m^2, mean REE 8·23 (SD 1·89) MJ/d, mean FFM 66·4 (SD 9·2) kg) recruited in our own metabolic ward. The slope is derived from the regression equation between REE and FFM or FM.

In order to divide intra-individual variance of REE in biological and methodological variability, analytical imprecision (I), bias (B) and total error (TE) were calculated according to Lacher *et al.* (2005) by using the following equations:

$$I = 0{\cdot}5\,CV_{intra};$$

$$B = 0{\cdot}25\left(CV^2_{intra} + CV^2_{inter}\right)^{1/2};$$

$$TE = kI + B, \text{ being } k = 1{\cdot}65 \text{ at } \alpha = 0{\cdot}05.$$

All measurements were made by the same trained observer (N. B.). The study protocol was approved by the ethical committee of the Christian-Albrechts-Universität zu Kiel. Each subject provided informed written consent before participation.

Results

Values for REE and REE_{adj} are given in Table 2. There were no significant differences in measured or REE_{adj} between the different time points.

There was no significant effect of the number of repeated measurements (one *v*. two *v*. three) on CV_{intra} of REE (Table 3). The high intraclass correlation coefficients of REE between two (r 0·77), three (r 0·75) and four (r 0·80) repeated measurements support these findings. However, within-subject standard deviation tends to decrease with increasing measurement recurrences.

The two protocols for REE assessment (standard *v*. optimised) are compared in Table 2. Both protocols differed significantly in the duration of the analysed period as well as in the variation in VO_2 per min, VCO_2 per min and REE. Mean CV_{intra} for measured REE in the standard and optimised protocol ranged from 5·0 (SD 3·4) (group 1) to 5·6 (SD 2·7) (group 2) and 5·1 (SD 2·6) % (group 3) to 5·4 (SD 2·6) % (group 2), respectively. Neither mean results for REE nor their respective CV_{intra} were different between the protocols. The intraclass correlation coefficients of REE in each group between both protocols were not different (range r 0·73–0·87). Thus, when compared with the standard protocol, the use of an optimised protocol did not result in a lower CV_{intra} of REE measurements.

In contrast to CV_{intra}, CV_{inter} of REE was high and ranged between 12·1 % (group 2) and 16·1 % (group 1; see Fig. 1). This was reduced to 13·6 % (group 1), 10·4 % (group 2) and 11·1 % (group 3) by adjusting REE for FFM and to 13·0, 10·2 and 10·7 % by adjusting REE for FFM and FM, respectively. The ratio of CV_{intra}:CV_{inter} of REE was 0·31 in group 1, 0·46 in group 2 and 0·38 in group 3. We calculated total error from analytical imprecision (2·6 %) and bias (3·7 %) to be 8 % of intra-individual variance in REE. CV_{intra} in FFM was calculated to be 1·4 %. Since 70 % of variance in REE is explained by FFM, CV_{intra} of REE_{adj} (5·2 %) can be divided into variance explained by FFM (1·0 %) and variance in metabolic rate (4·2 %).

Considering the subtle weight changes observed during follow-up investigations, CV_{intra} of predicted REE (model 1 and model 2) was about 0·5 %. When compared within a study group the results of the two predictions did not differ from each other (Table 2). However, both prediction equations underestimated actual REE by 10–15 %. The differences between measured and predicted REE values at all time points were statistically significant. The inaccuracy in REE measurements (mean difference between repeated measurements of individuals) in relation to inaccuracies of REE prediction (mean difference between measured and predicted REE) were −0·31/0·88 MJ/d for model 1 and −0·31/0·98 MJ/d for model 2 (calculated for group 1), respectively.

In an attempt to *a priori* identify individuals with a high CV_{intra} of REE measurements the variation of VO_2 per min, VCO_2 per min and REE within the entire 30 min of T0 REE measurement were correlated to CV_{intra} of REE measurements in groups 1, 2 and 3. There was no statistically significant correlation between CV_{intra} of REE and the CV of the individual calorimetric parameters within the entire 30 min of T0 REE measurement in all groups. A subgroup of eight subjects from group 1 had a high CV_{intra} of REE measurements defined as CV_{intra} above 5·0 %. Compared with the remaining fifteen subjects with a CV_{intra} under 5·0 %, this group had no significantly higher variation in VO_2 per min (P=0·925), VCO_2 per min (P=0·238) and REE (P=0·776) within the 30 min calorimetry period of T0, respectively.

Discussion

Neither the number of repeated measurements nor the type of protocol for data analysis has an influence on CV_{intra} of REE. The CV in repeated REE measurements (CV_{intra}) was approximately 5 % in our subjects. This result is in agreement with previous studies where CV_{intra} ranged between 1·3 and 6·0 % (Table 4). With the exception of Rieper *et al.* (1993) and Figueroa-Colon *et al.* (1996), most studies only had short measurement periods (<2 weeks).

There were no significant differences in REE between repeated measurements (T0–T3) within 6 months (October–March). These results are in agreement with Rieper *et al.* (1993), who did not find any differences in the mean values for repeated REE measurements within 1 year. There is no evidence of a seasonal effect on REE (Goran *et al.* 1998).

Table 2. Resting energy expenditure (REE) and mean intra-individual coefficients of variation (CV_{intra}) in different protocols (standard and optimised protocol) and numbers of repeated measurements (groups 1, 2 and 3)
(Mean values and standard deviations)

	Group 1 (*n* 23)							Group 2 (*n* 17)								
	T0		T1		CV_{intra} (%)			T0		T1		T2		CV_{intra} (%)		
	Mean	SD	Mean	SD	Mean	SD	SD_w	Mean	SD	Mean	SD	Mean	SD	Mean	SD	SD_w
Standard protocol																
Period analysed (min)	15	0	15	0				15	0	15	0	15	0			
VO_2 (ml/min)	292	44	299	50	5·0	3·4		280	32	284	39	287	32	5·6	2·5	
VCO_2 (ml/min)	255	44	275	53	7·4	5·6		242	32	262	40	259	31	8·2	4·0	
REE (MJ/24 h)	8·62*†	1·31	8·94*†	1·52	5·0	3·4	0·55	8·27[12]	0·97	8·47*†	1·17	8·54*†	0·95	5·6	2·7	0·54
REE_{adj} (MJ/24 h)	8·65	1·08	8·99	1·31	5·0	3·2	0·55	8·38	0·81	8·59	1·04	8·67	0·83	5·5	2·6	0·54
Optimised protocol																
Period analysed (min)	12‡	6	13[3]	5				14‡	6	13‡	6	12‡	5			
VO_2 (ml/min)	287	43	297	53	5·6	4·0		277	32	280	40	283	30	5·5	2·7	
VCO_2 (ml/min)	253	43	274	53	6·7	5·7		240	33	261	39	254	29	7·5	4·4	
REE (MJ/24 h)	8·50*†	1·27	8·87*†	1·57	5·3	3·9	0·61	8·19*†	0·95	8·38*†	1·19	8·41*†	0·89	5·4	2·6	0·52
REE_{adj} (MJ/24 h)	8·53	1·04	8·91	1·36	5·4	3·9	0·61	8·31	0·80	8·49	1·05	8·55	0·78	5·4	2·5	0·52
REE prediction																
Model 1 (MJ/24 h)	7·81	0·91	7·78	0·88	0·5	0·4		7·44	0·50	7·43	0·51	7·47	0·50	0·6	0·4	
Model 2 (MJ/24 h)	7·72	0·88	7·69	0·85	0·5	0·4		7·37	0·51	7·36	0·51	7·39	0·51	0·5	0·4	

	Group 3 (*n* 11)									
	T0		T1		T2		T3		CV_{intra} (%)		
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	SD_w
Standard protocol											
Period analysed (min)	15	0	15	0	15	0	15	0			
VO_2 (ml/min)	283	38	285	43	280	33	285	43	5·3	2·1	
VCO_2 (ml/min)	245	36	261	43	257	34	253	41	7·2	3·8	
REE (MJ/24 h)	8·36*†	1·13	8·52*†	1·31	8·38*†	1·00	8·46*†	1·29	5·2	2·4	0·50
REE_{adj} (MJ/24 h)	8·47	0·91	8·63	1·10	8·50	0·80	8·58	1·08	5·1	2·4	0·50
Optimised protocol											
Period analysed (min)	12‡	6	12‡	5	12‡	5	12‡	5			
VO_2 (ml/min)	278	38	281	44	276	31	281	41	5·2	2·5	
VCO_2 (ml/min)	243	35	259	43	253	33	247	39	6·9	4·1	
REE (MJ/24 h)	8·23*†	1·12	8·40*†	1·33	8·25*†	0·95	8·33*†	1·22	5·1	2·6	0·50
REE_{adj} (MJ/24 h)	8·35	0·89	8·50	1·10	8·37	0·77	8·45	1·01	5·0	2·6	0·50
REE prediction											
Model 1 (MJ/24 h)	7·38	0·60	7·37	0·62	7·41	0·61	7·42	0·61	0·5	0·3	
Model 2 (MJ/24 h)	7·32	0·61	7·31	0·62	7·34	0·62	7·35	0·63	0·5	0·3	

SD_w, Within-subject standard deviation; VCO_2, CO_2 production; REE_{adj}, REE adjusted for fat-free mass.
To, baseline; T1, 37 ± 11d; T2, 95 ± 8d; T3, 170 ± 7d.
* Values were significantly different from REE prediction of model 1 (ANOVA and Bonferroni *post hoc* test).
† Values were significantly different from REE prediction of model 2 (ANOVA and Bonferroni *post hoc* test).
‡ Values were significantly different from the standard protocol (ANOVA and Bonferroni *post hoc* test).

Table 3. Comparison of two, three and four repeated resting energy expenditure (REE) measurements in group 3

(Mean values and standard deviations)

	Two measurements (T0 and T1)		Three measurements (T0, T1 and T2)		Four measurements (T0, T1, T2 and T3)	
	Mean	SD	Mean	SD	Mean	SD
n	11		11		11	
VO_2 (ml/min)	280	39	278	35	279	36
VCO_2 (ml/min)	251	37	252	32	250	34
REE (MJ/24 h)	8·31	1·15	8·29	1·04	8·30	1·07
CV_{intra} (%)	5·5	3·4	5·6	2·8	5·1	2·6
SD_w (MJ)	0·57		0·55		0·50	
REE_{adj} (MJ/24 h)	8·43	0·92	8·41	0·81	8·42	0·84
CV_{intra} (%)*	5·4	3·4	5·5	2·8	5·0	2·6
SD_w (MJ)*	0·56		0·54		0·50	

VCO_2, CO_2 production; CV_{intra}, intra-individual CV; REE_{adj}, REE adjusted for fat-free mass; SD_w, within-subject SD.

To, baseline; T1, 37 ± 11d; T2, 95 ± 8d; T3, 170 ± 7d.

* Corresponding to REE_{adj}.

Day-to-day differences in REE are due to the summed effects of biological variability and methodological error (Melanson *et al.* 2004). Errors of REE measurement may be introduced by air leaks, incorrect calibration of the calorimeter, involuntary hyper- and hypoventilation, fluctuating levels of fractional inspired O_2 concentration, or acid–base disturbances (McClave *et al.* 2003). For the present data intra-individual variation in REE was partitioned in biological variability that we wish to characterise as precisely as we can and methodological variability that we wish to decrease as much as we can. The latter contributes 8 % to intra-individual variation. Variance in body composition (CV_{intra} FFM) explains 19 % of variability in REE adjusted for FFM whereas the remaining 81 % is explained by the variability of the metabolic rate (CV_{intra} REE).

In the present study, three or four measurements did not significantly improve CV_{intra} of REE when compared with two measurements (Table 3). Thus, our data show that the number of repeated measurements only marginally influenced measurement error and had no impact on CV_{intra} of REE. We assumed that using an optimised protocol of data analysis would reduce methodological variability and thus CV_{intra} in REE due to lower variation in VO_2 per min, VCO_2 per min and REE. However, the present results indicate that the type of REE data analysis (standard *v.* optimised protocol) has no effect on CV_{intra} of REE. This suggests that standardised measurement conditions (optimised protocol) during indirect calorimetry does not ensure a greater level of accuracy in REE results. However, the advantage of the optimised protocol might have been offset by the shorter period of time analysed (optimised protocol, mean of 12 min ranging from 5 to 22 min *v.* standard protocol, 15 min), which might have resulted in an increasing variation in REE (Reeves *et al.* 2004). We conclude that stability in gas-exchange parameters does not add to between-day variations of REE. Although REE measurements are performed under strictly standardised conditions, biological intra-individual variation in REE might also be due to variations in feeding, drinking, or activity pattern in the days before the REE measurements (Weststrate, 1993).

One aim of the present study was to investigate whether subjects with a high CV_{intra} of REE might already be identified by the first measurement due to higher values of calorimetry parameters (variation in VO_2 per min, VCO_2 per min and REE).

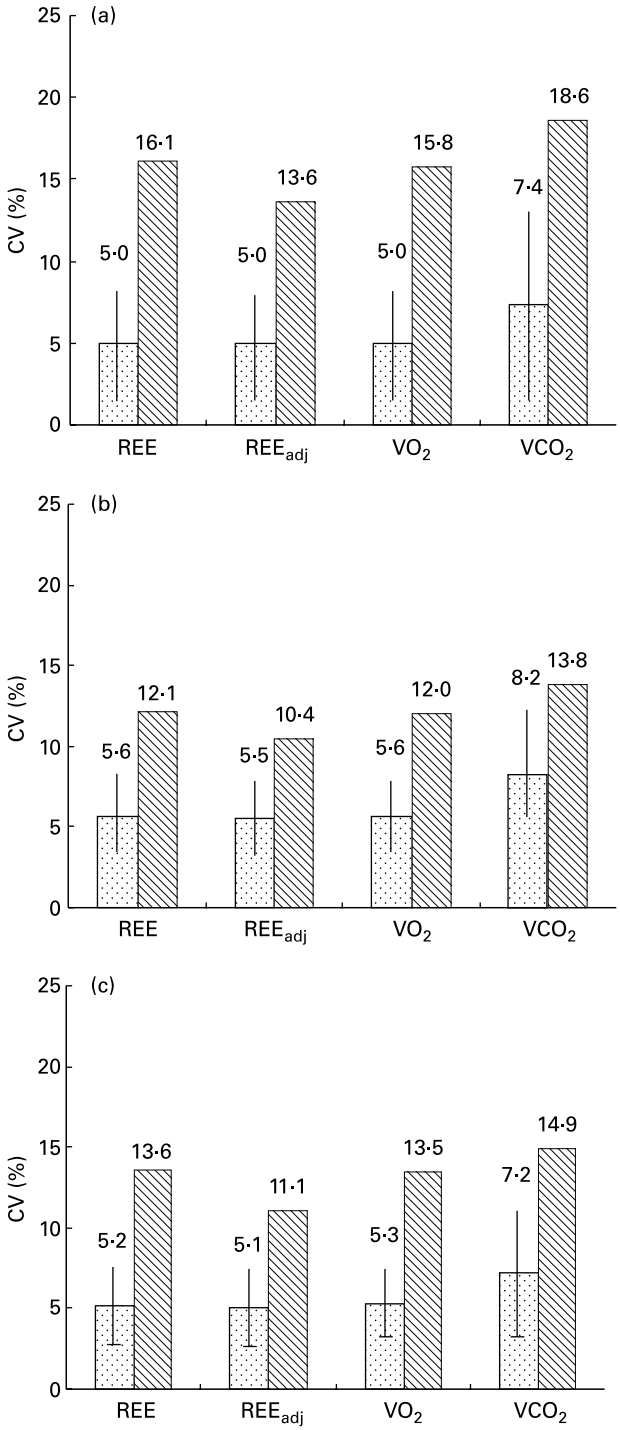

Fig. 1. Intra-individual CV (▨) and interindividual CV (▧) for resting energy expenditure (REE), REE adjusted for fat-free mass (REE_{adj}), VO_2 and CO_2 production (VCO_2) for different groups (group 1, two measurements (a); group 2, three measurements (b); group 3, four measurements (c)).

However, we could not find any association between CV_{intra} and these calorimetry parameters.

CV_{inter} in our subjects (group 1, 16·1 %; group 2, 12·1 %; group 3, 13·6 %) was approximately twice to threefold as high as CV_{intra} (Fig. 1). Similar values were obtained by others (Rieper *et al.* 1993; Figueroa-Colon *et al.* 1996; Black & Cole, 2000; Adriaens *et al.* 2003). Thus, these results demonstrate that there are true

Table 4. Mean intra-individual coefficients of variation (CV_{intra}) for resting energy expenditure measurements as observed in previous studies

Reference	Sex (*n*)		Age range (years)	Number of measurements		Period analysed or time of indirect calorimetry	Indirect calorimetry system	CV_{intra} (%)
	Male	Female		*n*	Period			
Rieper *et al.* (1993)	–	11	14–15	4	Within 1 year	7–14 min	Face mask	4·3
Rumpler *et al.* (1990)	4	–	30–48	5	Consecutive days	24 h	Chamber	2·4
Rumpler *et al.* (1990)	5	–	33–58	5	Within 1–3 weeks	24 h	Chamber	2·9
Murgatroyd *et al.* (1987)	4	–	n.s.	12	Consecutive days	24 h	Chamber	5·9
Zurlo *et al.* (1986)	5	4	17–29	6	Within 1 d	30 min	Ventilated hood	1·3
Figueroa-Colon *et al.* (1996)	–	19	6–10	2 × 3	On consecutive days, 6 weeks apart	30 min	Ventilated hood	5·8
Weststrate (1993)	49	–	20–45	4–6	Every 2–4 d	60 min	Ventilated hood	6·0
Garby *et al.* (1984)	22	–	n.s.	2	Within 2 d	n.s.	n.s.	2·4
Garby & Lammert (1984)	23	–	n.s.	2	Within 1 week	n.s.	n.s.	2·2
Ventham & Reilly (1999)	9	9	6–12	3	Within 1 week	12–16 min	Ventilated hood	2·6
Adriaens *et al.* (2003	8	11	F: mean 24, M: mean 23	3	Within 2 weeks	20 min	Ventilated hood	3·3
Haugen *et al.* (2003)	10	24	F: mean 37, M: mean 40	2	Within 2 weeks	15–20 min	Ventilated hood	4·5
Bell *et al.* (1999)	12		n.s.	3	Within 2 weeks	40 min	Ventilated hood	2·4–2·9
Present study	23	–	21–43	2–4	Within 6 months	30 min	Ventilated hood	5·2–5·4

F, female; M, male; n.s., not specified.

biological between-subject differences in REE. Sources of biological variation in REE are age, weight, body composition, sex, food intake, genetics, activity and physical conditioning (Rumpler *et al.* 1990). The main determinant of REE is FFM, explaining 60–70 % of CV_{inter} (Tataranni & Ravussin, 1995, Müller *et al.* 2004). In the study groups, CV_{inter} in REE adjusted for FFM was 13·6 % (group 1), 10·4 % (group 2) and 11·1 % (group 3), respectively. After adjusting for further covariates, such as fat mass, age and sex, REE still varies among subjects, leaving 19 % variance in REE unexplained (Ravussin *et al.* 1986). The present data show that CV_{inter} was reduced by 3 % after adjusting for FM and FFM.

Underestimation of REE by the two prediction equations was high in our subjects. This is probably due to subjects' characteristics, since young men at the age of 30 years usually have a high REE and our prediction equations were derived from subjects of both sexes and a broad age range (44·2 ± 17·3 years; Müller *et al.* 2004).

REE and RQ are reported to be a predictor of long-term weight change by some authors (Ravussin *et al.* 1988; Zurlo *et al.* 1990; Seidell *et al.* 1992; Valtuena *et al.* 1997). A study by Weyer *et al.* (1999) also found an association between REE and long-term weight gain whereas others did not find any association between weight gain and REE or RQ (Weinsier *et al.* 1995). Discrepancies in the results of different studies may be due to a lack of statistical power for verification of subtle between-group differences because of a high CV_{intra}. For instance regarding our own data, a CV_{intra} of 5 %, a between-group difference of 0·43 MJ/d and a mean standard deviation of 9 % would have required ninety-seven subjects to identify significant between-group differences. A high CV_{intra} thus reduces the power in statistical analyses of differences in REE. Therefore, the verification of subtle between- or within-group differences (i.e. differences in specific REE between sexes or a lower REE of 13–17 kJ/kg FFM due to weight reduction (Leibel *et al.* 1995) will require a considerable number of subjects.

In conclusion, in young healthy men we found a high CV_{intra} of REE measurements that was neither influenced by type of protocol for data analysis nor by the number of repeated measurements. About 20 % of the variance in REE_{adj} is explained by variance in body composition.

Acknowledgements

The present study was financially supported by the Deutsche Forschungsgemeinschaft (DFG Mü 714/1-8), by Precon Bickenbach, Germany and also by the Graduiertenkolleg 820 'Natürliche Antioxidantien – ihr Wirkungsspektrum in Pflanze, Tier, Lebensmittel und Mensch'.

References

Adriaens MPE, Schoffelen PFM & Westerterp KR (2003) Intra-individual variation of basal metabolic rate and the influence of daily habitual physical activity before testing. *Br J Nutr* **90**, 419–423.

Anonymous (1985) Energy and protein requirements. Report of a joint FAO/WHO/UNU Expert Consultation. *World Health Organ Tech Rep Ser* **724**, 1–206.

Bell SC, Elborn JS, Nixon LE, Macdonald IA & Shale DJ (1999) Repeatability and methodology of resting energy exenditure in patients with cystic fibrosis. *Respir Physiol* **115**, 301–307.

Black AE & Cole TJ (2000) Within- and between-subject variation in energy expenditure measured by the doubly-labelled water technique: implications for validating reported dietary energy intake. *Eur J Clin Nutr* **54**, 386–394.

Bland JM & Altman DG (1996) Measurement error. *BMJ* **312**, 1654.

Figueroa-Colon R, Franklin FA, Goran MI, Lee JY & Weinsier RL (1996) Reproducibility of measurement of resting energy expenditure in prepubertal girls. *Am J Clin Nutr* **64**, 533–536.

Garby L & Lammert O (1984) Within-subjects between-days- and weeks variation in energy expenditure at rest. *Hum Nutr Clin Nutr* **38**, 395–397.

Garby L, Lammert O & Nielsen E (1984) Within-subjects between-weeks variation in 24-hour energy expenditure for fixed physical activity. *Hum Nutr Clin Nutr* **38**, 391–394.

Goran MI, Nagy TR, Gower BA, Mazariegos M, Solomons N, Hood V & Johnson R (1998) Influence of sex, seasonality, ethnicity, and geographic location on the components of total energy expenditure in young children: implications for energy requirements. *Am J Clin Nutr* **68**, 675–682.

Harris JA & Benedict FG (1919) *A Biometric Study of Basal Metabolism in Man*. Publication no. 279. Washington, DC: Carnegie Institute of Washington.

Haugen HA, Melanson EL, Tran ZV, Kearney JT & Hill JO (2003) Variability of measured resting metabolic rate. *Am J Clin Nutr* **78**, 1141–1144.

Lacher DA, Hughes JP & Carroll MD (2005) Estimate of biological variation of laboratory analytes based on the Third Health and Nutrition Examination Survey. *Clin Chem* **51**, 450–452.

Leibel RL, Rosenbaum M & Hirsch J (1995) Changes in energy expenditure resulting from altered body weight. *N Engl J Med* **332**, 621–628.

McClave SA, Lowen CC, Kleber MJ, McConnel JW, Jung LY & Goldsmith LJ (2003) Clinical use of the respiratory quotient obtained from indirect calorimetry. *J Parenter Enteral Nutr* **27**, 21–26.

Melanson EL, Coelho LB, Tran ZV, Haugen HA, Kearney JT & Hill JO (2004) Validation of the BodyGem™ hand-held calorimeter. *Int J Obes* **28**, 1479–1484.

Müller MJ, Bosy-Westphal A, Klaus S, *et al.* (2004) World Health Organization equations have shortcomings for predicting energy expenditure in persons from a modern, affluent population: generation of a new reference standard from a retrospective analysis of a German database of resting energy expenditure. *Am J Clin Nutr* **80**, 1379–1390.

Müller MJ, Bosy-Westphal A, Kutzner D & Heller M (2002) Metabolically active components of fat-free mass and resting energy expenditure in humans: recent lessons from imaging technologies. *Obes Rev* **3**, 113–122.

Murgatroyd PR, Davies HL & Prentice AM (1987) Intra-individual variability and measurement noise in estimates of energy expenditure by whole body indirect calorimetry. *Br J Nutr* **58**, 347–356.

Ravussin E & Bogardus C (1989) Relationship of genetics, age, and physical fitness to daily energy expenditure and fuel utilization. *Am J Clin Nutr* **49**, 968–975.

Ravussin E, Lillioja S, Anderson TE, Christin L & Bogardus C (1986) Determinants of 24-hour energy expenditure in man. *J Clin Invest* **78**, 1568–1578.

Ravussin E, Lillioja S & Knowler WC (1988) Reduced rate of energy expenditure as a risk factor for body-weight gain. *N Engl J Med* **318**, 467–472.

Reeves MM, Davies PSW, Bauer J & Battistutta D (2004) Reducing the time period of steady state does not affect the accuracy of energy expenditure measurements by indirect calorimetry. *J Appl Physiol* **97**, 130–134.

Rieper H, Karst H, Noack R & Johnsen D (1993) Intra- and inter-individual variations in energy expenditure of 14–15-year-old schoolgirls as determined by indirect calorimetry. *Br J Nutr* **69**, 29–36.

Rumpler WV, Seale JL, Conway JM & Moe PW (1990) Repeatability of 24-h energy expenditure measurements in humans by indirect calorimetry. *Am J Clin Nutr* **51**, 147–152.

Seidell JC, Muller DC, Sorkin JD & Andres R (1992) Fasting respiratory exchange ratio and resulting metabolic rate as predictors of weight gain: the Baltimore Longitudinal Study on Aging. *Int J Obes* **16**, 667–674.

Soares MJ & Shetty PS (1986) Intra-individual variations in resting metabolic rates of human subjects. *Hum Nutr Clin Nutr* **40**, 365–369.

Tataranni PA & Ravussin E (1995) Variability in metabolic rate: biological sites of regulation. *Int J Obes Relat Metab Disord* **19**, Suppl. 4, 102–106.

Valtuena S, Salas-Salvado J & Lorda PG (1997) The respiratory quotient as a prognostic factor in weight-loss rebound. *Int J Obes* **21**, 811–817.

Ventham CJ & Reilly JJ (1999) Reproducibility of resting metabolic rate measurement in children. *Br J Nutr* **81**, 435–437.

Weinsier RL, Nelson KM, Hensrud DD, Darnell BE, Hunter GR & Schutz Y (1995) Metabolic predictors of obesity. *J Clin Invest* **95**, 980–985.

Weir JB (1949) New methods for calculating metabolic rate with special reference to protein metabolism. *Nutrition* **6**, 213–221.

Weststrate JA (1993) Resting metabolic rate and diet-induced thermogenesis: a methodological reappraisal. *Am J Clin Nutr* **58**, 592–601.

Weyer C, Pratley RE, Salbe AD, Bogardus C, Ravussin E & Tataranni PA (1999) Energy expenditure, fat oxidation, and body weight regulation: a study of metabolic adaption to long-term weight change. *J Clin Endocrinol Metab* **85**, 1087–1094.

Zurlo F, Lillioja S & Espesito-del Puente A (1990) Low ratio of fat to carbohydrate oxidation as predictor of weight gain: study of 24-h RQ. *Am J Physiol* **259**, E650–E657.

Zurlo F, Schutz Y, Frascarolo P, Enzi G, Deriaz O & Jequier E (1986) Variability of resting energy expenditure in healthy volunteers during fasting and continuous enteral feeding. *Crit Care Med* **14**, 535–539.